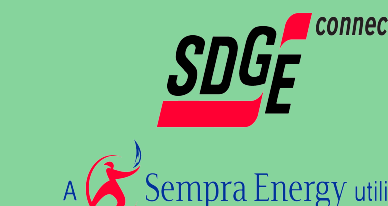


reschwartz@ucsd.edu
tenaya.ucsd.edu/~rschwartz

Exploring Meteorological and Climatic Conditions Driving California Coastal Marine Layer Clouds

Rachel E. Schwartz¹, Lukas Nonnenmacher², Vladimir Kostylev³, Sam F. Iacobellis¹, Alexander Gershunov¹

1. Climate, Atmospheric Science and Physical Oceanography, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA, United States. 2. Mechanical and Aerospace Engineering, University of California, San Diego, La Jolla, CA, United States. 3. Green Power Labs Inc., Dartmouth, NS, Canada



Abstract

We describe the spatial variability of southern California marine layer clouds and study the daily and intradaily relationships between the cloud extent and meteorological variables. We utilize a record of low level clouds derived from GOES imagery, radiosonde measurements, and a regional dynamical downscaling of a global reanalysis. Strong diurnal, intraseasonal, and interannual variability are observed through the half hourly daytime record of MJJA 2007-2010. EOF analysis on albedo confirms the importance MLC to the region. We find at the immediate coast, morning marine layer cloud presence is largely explained by inversion strength and cloud thickness, while inversion base height plays a more pivotal role in marine layer cloud daily inland extent. Night and early morning times when the winds (in or above the inversion) are from the south compared to northwest are associated with more inland extent of the cloud layer throughout the day. Periods of southerly winds are in turn found to be associated with higher inversion bases than during northwesterly flow.

The coldest winter I ever spent was a summer in San Francisco

Background: Low marine stratus clouds, often referred to as marine layer clouds (MLCs), are a persistent regional feature of California coastal summer climate. Their presence modulates summertime heat, while their unanticipated absence during a heat wave can lead to health risks as occurred in July 2006. The low level cloud layer responds to a combination of global and regional climate and weather as well as local topography. MLC dynamics should therefore reflect sensitivities to a range of physical influences on global, regional, and local scales.

Methods: This work utilizes Geostationary Operational Environmental Satellite (GOES) observations at half hourly daytime, 1km resolution over southern California for May, June, July, August (MJJA) 2007 - 2010. For Fig. 2 cloudiness was determined using a threshold (22%) of cloud albedo after removing clear skies albedo for each grid cell and time step. Although an albedo only cloud identification does not guarantee low cloud only (see ongoing research), for the season and region most cloud cover is the low cloud of interest, as is confirmed by the cloud layer's spatial relation to elevation. Figs. 5 & 6 additionally used GOES IR images to identify low clouds (dataset created by Green Power Labs Inc., Kostylev et al., 2012). A Morning Coastal MLC index (Fig. 5) is made by taking the average of the 8 - 11:30 PST spatial extent values for a swath of low elevation (< 50 m) immediate coastal land (≤ 3 km of the coastline). Inversion properties are defined consistently with conventions (Iacobellis et al. 2009). Cloud thickness is defined as the difference between inversion base height and lifting condensation level (LCL) using the approximation method of Lawrence 2005.

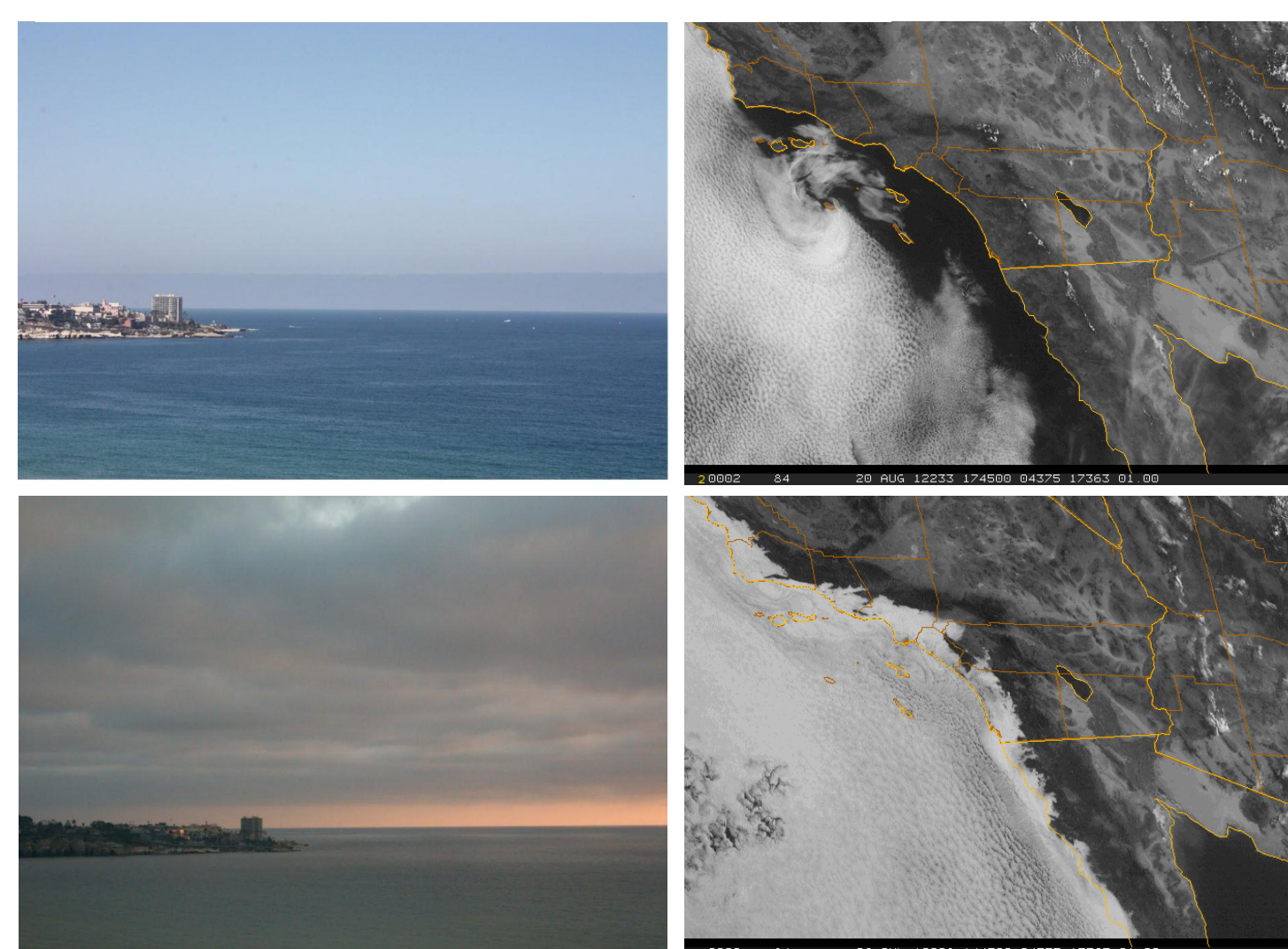


Figure 1: Photographs taken from Scripps Institution of Oceanography in summer 2012 providing a view from the coast and representative GOES visible satellite example images providing a view from above, depicting the cloud layer offshore (top) and extending over low elevation coastal land (bottom).

Data Sources: Sounding data to examine the relationships between the atmospheric vertical structure (in particular inversion properties) and the marine layer cloud behavior was provided by the NOAA/ ESRL Radiosonde Database twice daily at 4 and 16 PST at Miramar station (NKX; WMO ID: 72293). Inversion properties were calculated for MJJA 2000 - 2010. Subsidence inversion (hereafter inversions) are defined as inversions with base above ground level and below 700 mb. Winds at 925 mb and 850 mb were obtained from California Reanalysis Downscaling at 10km. CaRD10, a downscaled reanalysis product (Kanamitsu and Kanamaru, 2007) was developed for regional scale global change research and application, and captures the Catalina Eddy which is known to increase MLC extent (Mass and Albright, 1989).

Ongoing & Future Research



Currently, we are working on creating an enhanced low cloud record (1996 - 2011) derived from GOES half hourly observations for the complete California and offshore region for both day and night. The cloud detection will allow for discrimination of low clouds from other cloud types through differences in the GOES shortwave and longwave IR channels. We are currently testing thresholds to optimize the cloud tests for GOES channels, and our focus (low clouds in the summer season of coastal California) and validating with hourly airport cloud cover and base observations at seven coastal airports from Crescent City to San Diego. The addition of nighttime observations will enable us to describe the MLC diurnal cycle in more detail, and assess impacts of diurnal variation on e.g. daily maximum temperatures.

A Persistent yet Variable Feature

The marine stratus has a typical diurnal cycle in which its inland extent is greatest in the morning, it then recedes coastally into the afternoon. The coast was cloudy ~70% of 2007-2010 summer mornings at 6:30 PST, this was reduced to ~40% by 10 PST for the immediate coast, and even less just slightly inland (**Fig. 2b**). The colloquialisms May Gray and June Gloom describe the persistent cloudiness of these months overland, while MLC presence is maintained over the immediate coast and offshore waters in July (**Fig. 2c**). Variability between seasonal cloudiness exists with 2010 being the cloudiest of the four summers (**Fig. 2d**). In fact, July 2010 was the cloudiest July in 50 years according to observations of low level cloudiness at San Diego Airport. Not surprisingly from the 4 year averages, the leading Empirical Orthogonal Function (EOF) from daytime MJJA 2010 GOES-albedo (cloudiness), representing 67% of total variance, is clearly a marine and coastal pattern (**Fig. 3a**). The signature of the low clouds can be seen in the leading edge's sensitivity to elevation. This preliminary analysis confirms that MLCs are the most dominant factor in the variance of cloudiness during summer in this region and provides quantitative evidence of the cloud layer's significance.

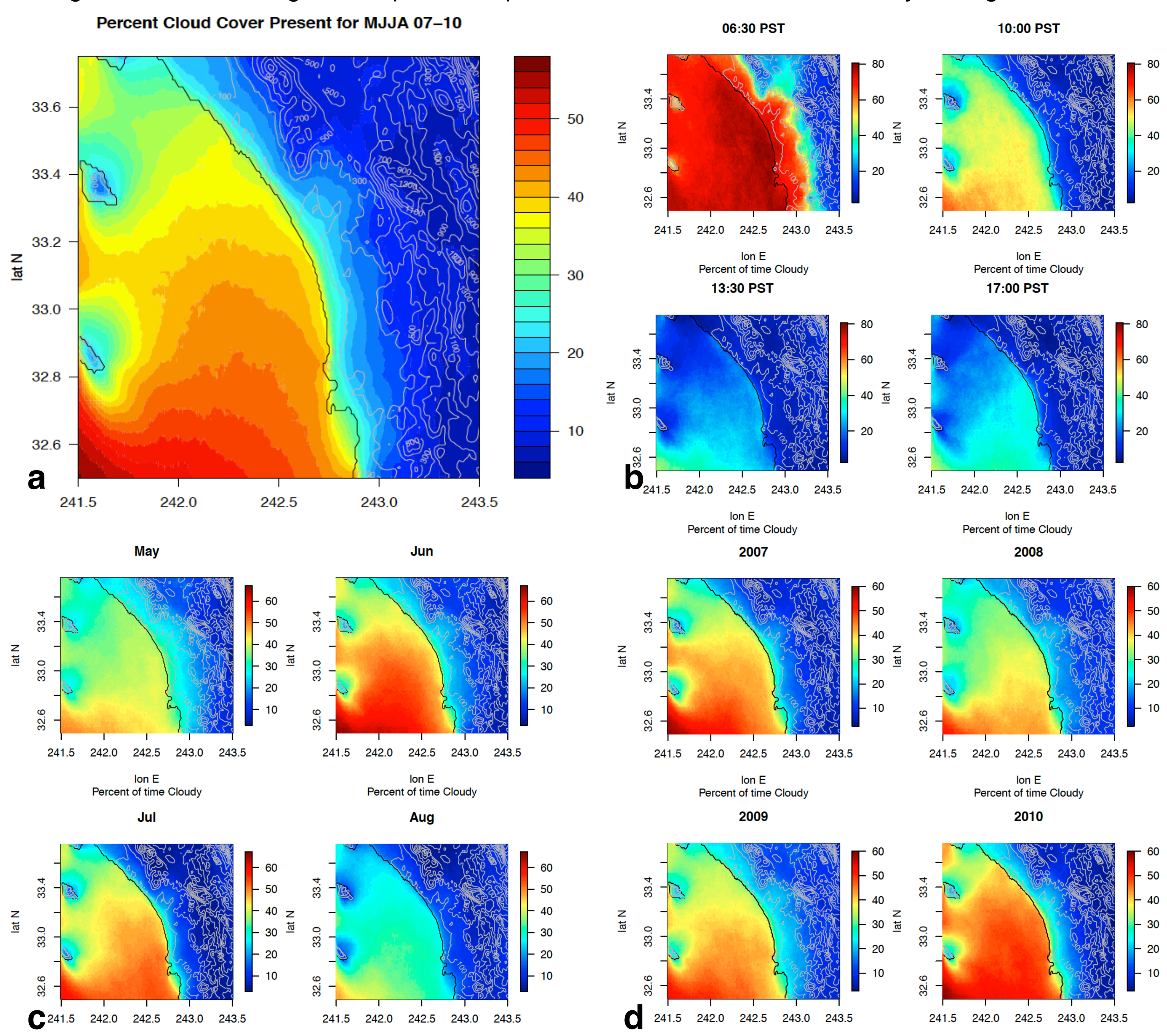


Figure 2: Maps of southern California showing the percent of time cloudy (at 1 km GOES grid resolution) for (a) MJJA 2007-2010 daylight hours (6:30-17 PST) (b) MJJA 2007-2010 6:30 PST (top left), 10:00 PST (top right), 13:30 PST (bottom left), and 17:00 PST (bottom right) (c) 2007-2010 daylight hours of May (top left), June (top right), July (bottom left), and August (bottom right) and (d) MJJA daylight hours of 2007 (top left), 2008 (top right), 2009 (bottom left), and 2010 (bottom right). The coast is shown in black, and gray contours are local topography starting at 100m with intervals by 200m.

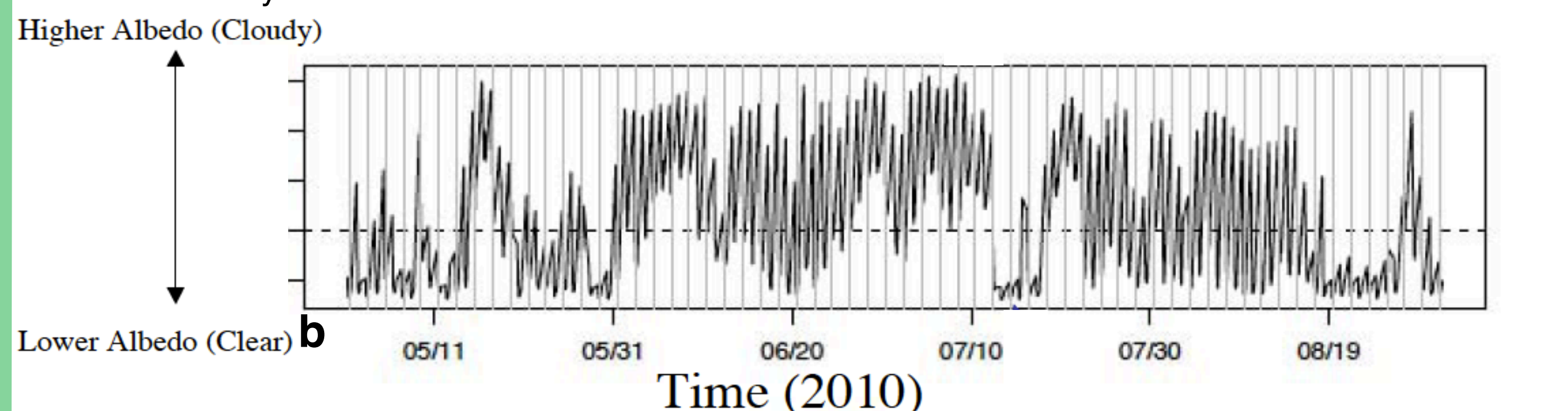


Figure 3: (a) Leading EOF, representing 67% of variance, for half hourly daylight (6:30-17 PST) summer (MJJA) 2010 GOES derived albedo for southern California. Units are correlation coefficient (r) between the (b) leading Principal Component (PC) time series and the satellite albedo data.

Driving Variables from Above & Below

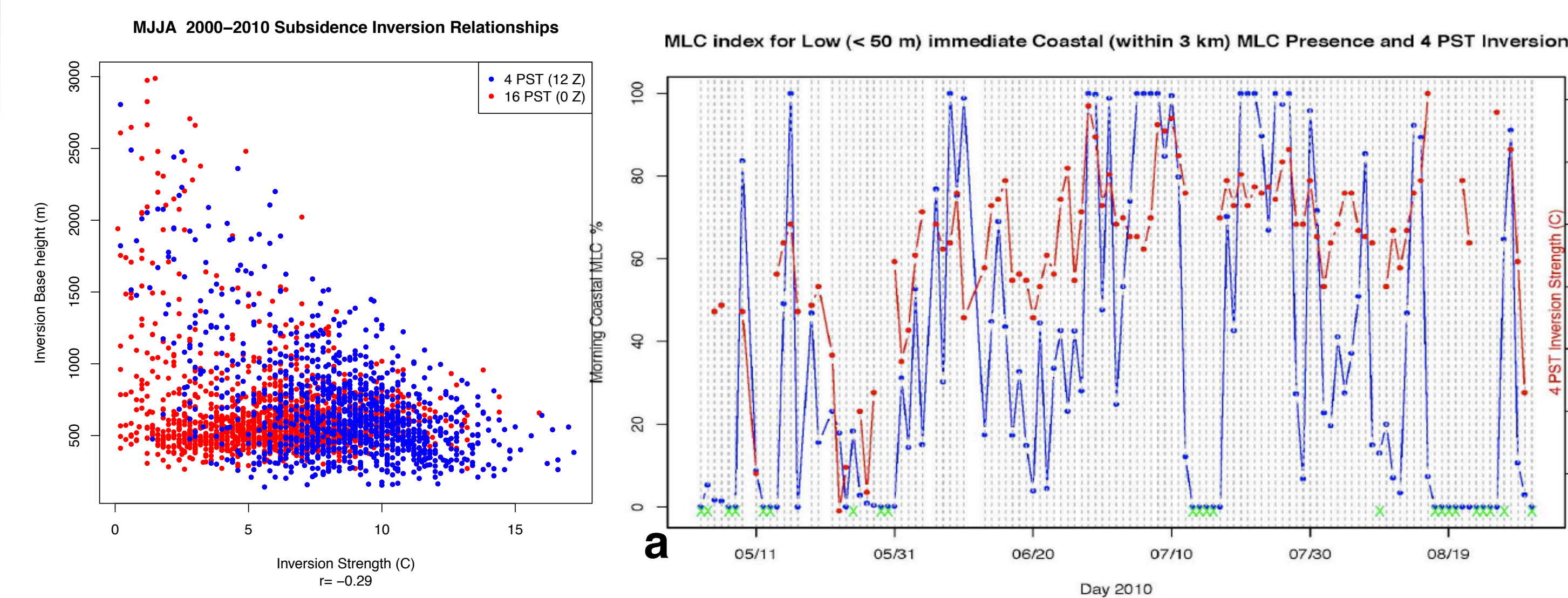
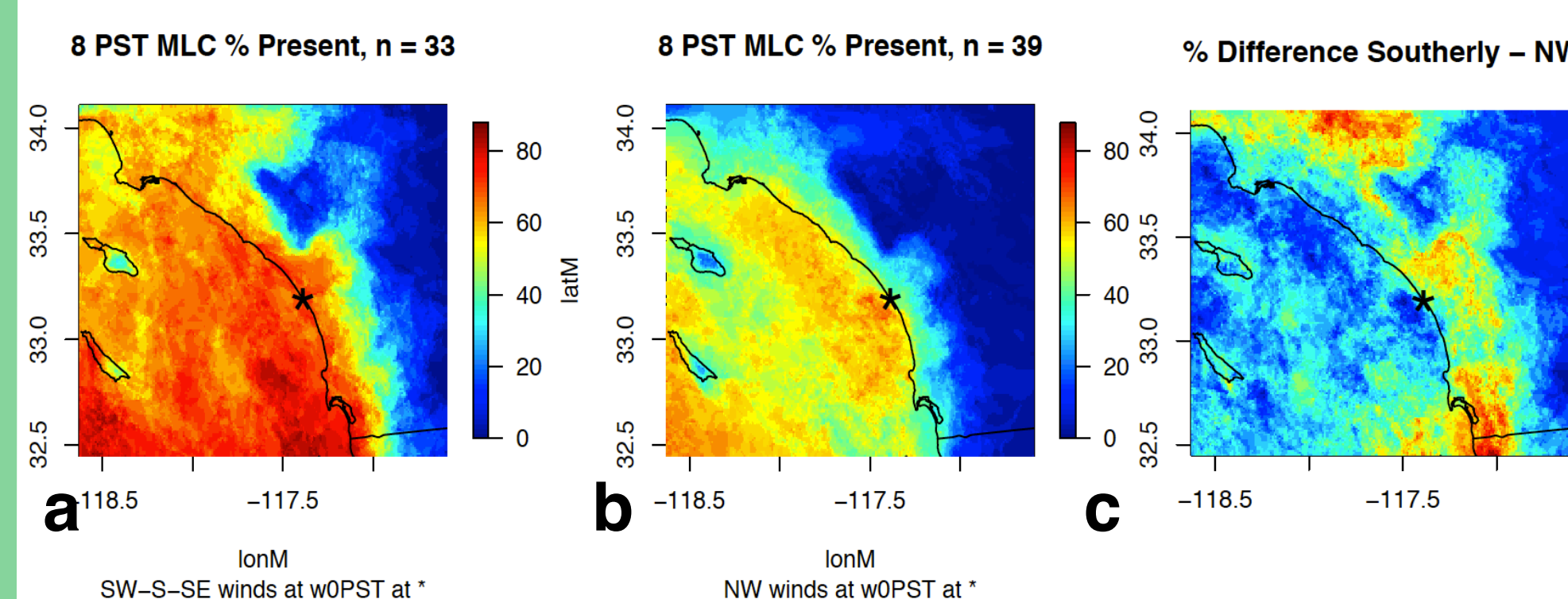


Figure 4 (above): Relationship between inversion base height and strength for MJJA 2000 - 2010 inversions for 4 PST (blue) and 16 PST (red).

An essential ingredient to the formation and persistence of MLCs is a strong temperature inversion which acts to inhibit vertical air motion and thus, cap the cloud layer. The likelihood of inversion occurrence over the region is high (90.1% of observations over 11 summers). While almost always present, the inversion properties vary as shown in the **Fig. 4** for inversion base height and strength. Inversion strength is generally greater at nighttime (4 PST) than daytime (16 PST), and stronger inversions tend to have a lower base height. As seen in **Fig. 5a** 2010 days without an inversion at 4 PST overlap with completely cloud free mornings. **Fig. 5b** illustrates that weaker inversions are associated with lower likelihood of MLC; outliers in the inversion strength and MLC index relationship are explained by anomalous cloud thickness values (including negative values in dark blue).



To investigate the influence of wind direction on the spatial extent of MLC, cloud images were subsetted for 925 mb (generally within the inversion) winds from the NW (285° to 345°) and the S (105° to 255°) at a coastal CaRD10 grid. From the composite maps it is apparent (**Fig. 6**) that S wind nights are associated with greater inland extent of the cloud layer. For MLC inland extent at 8 PST, the percentage of cloudy land area is 8.46% for NW compared to 36.43% for S wind direction, both at 0 PST. When the wind field maps are examined it is found that often these coastal southerly winds are part of an eddy circulation. S winds are associated with higher inversion bases than NW winds (**Fig. 7**).

Figure 6 (left): Composite maps showing the percent of time a low cloud is present for (a) S and (b) NW 925 mb wind at 0 PST at location marked by * (c) difference of (a) & (b).

Acknowledgments & References

Support was provided through 2011 & 2012 summer internships with SDGE and Green Power Lab Inc. and a 2012 - ongoing NASA Earth and Space Science Fellowship (NASA 12-EARTH12F_0080). R.E.S gratefully acknowledges these funding sources and Dallas Cormier, Patrick Mathiesen, and Mary Tyree.

- Iacobellis, S. F. et al., 2009: Climate variability and California low-level temperature inversions. California Climate Change Center, Publication # CEC-500-2009-020-F
- Kanamitsu, M. and H. Kanamaru, 2007: 57-Year California Reanalysis Downscaling at 10km (CaRD10) Part 1. System Detail and Validation with Observations. *J. Climate*, 20, 5527-5552.
- Kostylev, V. et al., 2nd Int. Workshop on Integration of Solar Power into Power Systems, Lisbon, November 2012, Advancing Satellite-based Solar Power Forecasting Through Integration of Infrared Channels for Automatic Detection of Coastal Marine Inversion Layer
- Lawrence, M. G. 2005: The Relationship between Relative Humidity and the Dewpoint Temperature in Moist Air, A simple Conversion and Applications. *B. Am. Meteorol. Soc.*, 86, 225-233.
- Mass, C. F. and M. D. Albright 1989: Origin of the Catalina Eddy, *Monthly Weather Review*, 117, 2406-2436
- "The coldest winter I ever spent was a summer in San Francisco." is often (incorrectly) attributed to Mark Twain.